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All-PM Monolithic fs Yb-Fiber Laser, Dispersion-Managed with All-Solid Photonic Bandgap Fiber

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Abstract: All-in-fiber SESAM-modelocked self-starting fiber laser is demonstrated. Cavity dispersion is managed by a spliced-in PM all-solid photonic bandgap fiber. The laser directly delivers 1.25 nJ pulses of 280 fs duration.

OCIS codes: (060.2320) Fiber optics amplifiers and oscillators; (140.3538) Lasers, pulsed

1. Introduction

In recent years an impressive progress was made in development of femtosecond Yb-fiber lasers. However, only a few monolithic, i.e. all-in-fiber, lasers with direct fiber-end fs pulse delivery were demonstrated so far (see e.g. [1], [2]). Here, the challenge lies in managing the dispersion both in and outside of the laser cavity without relying on mechanically unstable bulk-optics elements, such as grating pairs. In this work we demonstrate a laser using a novel PM all-solid photonic bandgap fiber (PM SC-PBG) [3], spliced into the cavity for intra-cavity dispersion management. The ex-cavity final pulse compression is performed in a spliced-on PM hollow-core photonic crystal fiber (PM HC-PCF) [4]. Both of these specialty fibers were obtained from Crystal Fibre A/S.

2. Laser design and performance

Our laser consists of a linear-cavity oscillator, single-mode amplifier, and a spliced-on pulse-compression HC-PCF, separated by fiber-optic isolators. All the fibers in our system, including the intra-cavity SC-PBG and compression HC-PCF, are polarization-maintaining. The laser layout is presented in Fig. 1. A non-monolithic solution for such a laser was shown earlier in [5], using a non-PM air-silica PCF in the cavity.

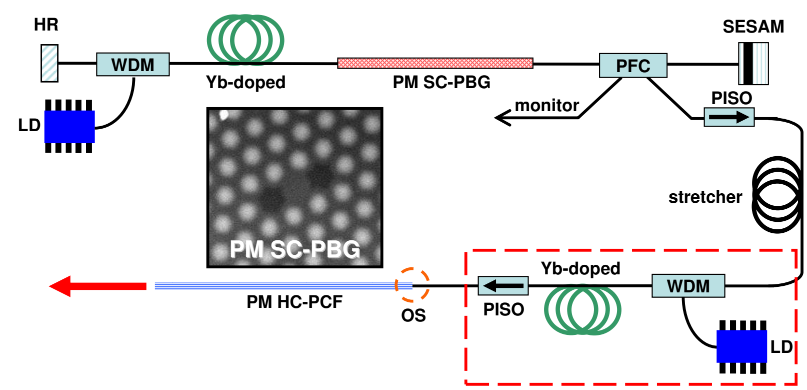

Fig. 1: Layout of the laser: HR - high-reflectivity pigtailed mirror, WDM - 980/1030 wavelength division multiplexer, LD - single-mode pumping diode at 974 nm, PM SC-PBG - PM all-solid photonic bandgap fiber, SESAM - semiconductor saturable absorber mirror, PISO - polarization-maintaining isolator, PFC - 80/20 polarization filter coupler, OS - optimized splice, HC-PCF - hollow-core photonic crystal fiber. Inset: SEM image of PM SC-PBG. Courtesy of J.K.Lyngsø, Crystal Fibre A/S.

The Yb-fiber oscillator cavity is capped with a high-reflectivity pigtailed mirror on one end, and a butt-coupled semiconductor saturable absorption mirror (SESAM) with 24% modulation depth on the other end. The SESAM ensures stable and self-starting modelocking of the laser in the pumping power range 60-82 mW, provided by a single-mode laser diode at 974 nm. Outcoupling is performed via 80/20 2x2 polarization filter coupling. The length of SMF, Yb-doped, and SC-PBG fibers used in the cavity was 1.6 m, 0.32 m, and 1.21 m, respectively, resulting in total cavity length of 3.13 m and oscillator repetition rate of 32.8 MHz.

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Anomalous dispersion in the laser cavity is provided by a polarization-maintaining hybrid TIR/bandgap all-solid PCF [3]. The SEM image of the fiber is shown in the inset of Fig. 1. The guidance in this fiber is based on the PBG effect, provided by undoped and Ge-doped silica rods, in one plane; and on TIR between undoped and Boron-doped silica stress rods in another plane. Undoped, Ge-doped, and Boron-doped silica regions are seen in the SEM inage as grey, light grey, and black areas, respectively. Stress rods provide the needed birefringence within the transparency window of the fiber at 1000 - 1075 nm, whereas the PBG structure provides the anomalous dispersion (see Fig. 2, (a)).

The oscillator was delivering sub-ps 12-pJ pulses with a bandwidth of 7.5 nm, centered at 1028.5 nm, as shown in Fig. 2, (a). At increase in the pump diode power, the central wavelength of the oscillator emission shifted towards longer wavelengths, which indicates the tendency of formation of stronger and longer pulses in the cavity, conforming to the higher net cavity dispersion (see Fig. 2, (a)).

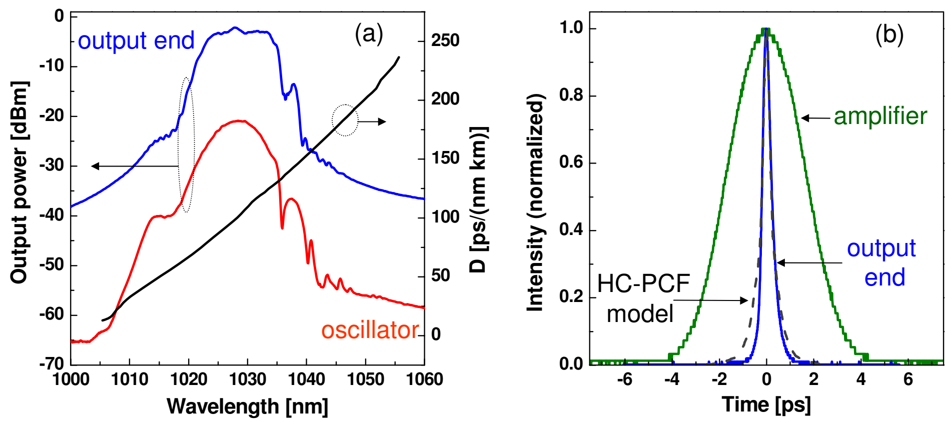

Fig. 2: a) Laser spectra measured after the oscillator (blue), and at the output end of the laser (red). Dispersion of PM SC-PBG (black), measured as described in [6]. b) Autocorrelation trace of the laser pulses at the end of the amplifier (green), and at the output end of the laser (blue). Calculated autocorrelation of the modelled [2] pulse (black dashed).

The isolated output of the oscillator was first stretched in a long piece of a standard PM SMF, and then launched into a single-mode amplifier with 21 dB amplification. Stretching was necessary to avoid the significant self-phase modulation (SPM) in the amplifier. The amplifier output was isolated, and then launched into the spliced-on compression HC-PCF. The HC-PCF-to-PM-SMF splice loss was 0.54 dB [7].

The autocorrelation (AC) of the amplifier output before the compression was found to have FWHM duration of 3.6 ps, corresponding to actual length of 2.55 ps. After propagating through the length-optimized HC-PCF of 4.07 m, the pulse at the output HC-PCF end of the laser had AC of 435 fs at FWHM, which corresponds to approximately 280 fs of actual duration. Both experimental optimal HC-PCF length and resulting pulse duration are very close to the theoretically predicted [2] values of 4.0 m and 293 fs, respectively. The measured ACs of the laser pulses before and after HC-PCF compression are presented in Fig. 2, (b), along with the calculated AC of the modelled pulse. The output pulse energy was 1.25 nJ, corresponding to 40 mW of cw power. Its spectrum has FWHM bandwidth of 12.5 nm (see Fig. 2, (a)). Our further efforts will be directed on achieving higher resulting pulse energies and shorter pulse durations, using e.g. large mode area amplification and laser bandwidth and dispersion optimization.

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